TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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METHODS OF VISUALLY DETERMINING THE AIR FLOW AROUND AIRPLANES

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SUMMARY

This report describes methods used by the National Advisory Committee for Aeronautics to study visually the air flow around airplanes. The use of streamers, oil and exhaust gas streaks, lampblack and kerosene, powdered materials, and kerosene smoke is briefly described. The generation and distribution of smoke from candles and from titanium tetrachloride are described in greater detail because they appear most advantageous for general application. Examples are included showing results of the various methods.

INTRODUCTION

Many methods have been employed in model investigations for the visual study of air flow around various objects. (References 1 to 9, inclusive.) Means of making similar investigations on a full-scale airplane at the air speeds obtained in flight have not been thoroughly developed although the advantages to be gained by them have long been realized. More concentrated attention has been given the problem recently by the National Advisory Committee for Aeronautics and some very promising results have been obtained. The purpose of this report is to describe the methods that have been employed in the study of air flow around airplanes in flight and to give in detail the latest developments.

PRELIMINARY TESTS

Streamers.- Probably one of the oldest known methods of air-flow study in flight consists of the observation of light strings or streamers. Wool tufts, silk threads, and like materials are secured by one end to either (1) the surface over which the flow is to be studied, (2) the struts, (3) the end of small streamline masts mounted on the surface, or (4) the end of a rod which can be moved around at will by the observer. (Reference 2.) This method gives an indication of the direction of the air flow and its smooth or turbulent nature. Examples of information obtained with streamers are shown in Figures 1, 2, and 3. Long streamers can not be relied upon to indicate true air-flow direction if the air-flow path is curved, as the tension in the streamer will cause it to conform more nearly to the chord of the arc.

Lampblack and kerosene.- The path of oil and exhaust gases over the surfaces behind engines can be seen on most airplanes and has often been traced, but the effects of gravity and the adhesion of the oil cause doubt as to the reliability of the information obtained. Furthermore, the resulting pattern is an indication of the flow only on the very surface. In spite of these inherent disadvantages these observations led to the decision to employ lampblack and kerosene as used in wind tunnels. This method consists of painting a thin mixture of lampblack and kerosene over the surface in streaks perpendicular to the general direction of the air flow and flying the airplane immediately so that the mixture sets and dries in flight. Examples of patterns obtained in this way are shown in Figure 4. This method was also used to study the air flow perpendicular to the surface by mounting a metal fin on the surface parallel to the air flow and obtaining a pattern on both sides of it. Figure 5 shows the pattern resulting when this method was applied to the study of air flow around an engine cowling. The limitations of this method are further emphasized here in that the flow on the fin is affected by the surface of the fin and is not entirely indicative of the free air.

Fine powder.- Powdered materials such as aluminum dust have been tried by releasing them into the air stream but the results were not satisfactory. An enormous quantity of the material was required to make the flow sufficiently dense for successful photography.

Kerosene vapor.- Smoke produced by heating kerosene vapor has frequently been used in flight to study air flow. A fairly dense smoke can be generated for long periods of time and the system is simple and operates smoothly. However, the distributing pipes must be well lagged to prevent condensation and also to prevent fire due to contact with parts of the airplane, and thus the adaptability of the method is reduced. The system is not recommended mainly because of the fire hazard caused by carrying the kerosene under pressure and at high temperatures. Figure 6 shows a kerosene smoke stream passing (a) through the propeller disk of an airplane on the ground and (b) over the nose of an airplane placed in the slipstream of another airplane.

Smoke candles.- Smoke candles designed for the military services for obscuring troop maneuvers have also been used with very satisfactory results. The candles are comparatively inexpensive, are easy to obtain, and require a simple installation to adapt them for use in flight. The latter reason is considered of sufficient importance to warrant the detailed description given later. However, as the time of burning is quite short, the control of the flow and the distribution of the smoke rather limited, and the fire hazard from burning particles is not negligible, a still better method was sought.

Titanium tetrachloride.- A study of the methods of smoke generation in model work reveals that even in wind tunnels difficulties are encountered in obtaining a smoke which will not diffuse so rapidly in low-speed air as to suffer a marked reduction in opacity, and yet one which can be generated in a continuous supply for a reasonable length of time. Titanium tetrachloride gives excellent results although considerable difficulty is experienced in handling this smoke-producing liquid. The advantageous features of the reagent led to the decision to use it in spite of the possible danger of corrosion of the metal parts of the airplane. Fortunately it is available in large quantities since it is also used for smoke-screen work in the military services. The manner in which smoke is generated from it is the second method of which a detailed description will be given.

SMOKE PRODUCED BY CANDLES

The candles used in these tests are the nontoxic type designated "HC., MI" and are fully described in reference 10. The candle consists of a rectangular tin box containing a solid smoke-producing mixture of powdered zinc, zinc oxide, and hexachlorethane; a starting mixture of potassium perchlorate, antimony, and zinc dust; and a match head of potassium chlorate, antimony sulphide, and dextrin. When the match head is fired it in turn ignites the starting mixture which starts a chemical reaction of the smoke-producing mixture, generating considerable heat with the formation of zinc chloride. The zinc chloride that escapes into the air readily absorbs moisture and forms highly light-obscuring liquid particles. The candle delivers a satisfactory volume of smoke for a period of from 2 to 4 minutes.

A metal box was made to hold two candles and a system of baffle plates was placed in the smoke exit to arrest possible particles of burning material. The box was placed on the end of a boom which was mounted on the right wing of a Fairchild cabin monoplane (FC2W-2) as shown in Figure 7. The location of the smoke box could be varied in flight by means of cables running to the cabin. It was found impracticable to conduct the smoke through long passages unless the zinc chloride was mixed with air immediately upon leaving the candle. In the present installation this was provided for by leaks in the joints of the smoke box.

The smoke flow was established in level flight and moving pictures of it were taken from both the cabin and from another airplane. Sample frames of these, with the smoke box in its lowest position, are reproduced in Figure 8. The attitude and speed of the airplane were determined by means of a statoscope, an inclinometer, and an air-speed meter.

Some precautions are necessary in the use of these smoke candles. If the candle is ignited on the ground no person should approach it closer than 10 feet. Although the candle is practically harmless, there is a tendency to throw out hot particles of the combustible mixture. In flight, if these escape from the box, they apparently cool quickly because no evidence has been found of hot particles striking the airplane. Before each flight the box should be thoroughly cleaned and dried because the starting mixture of the candle must be kept perfectly dry until ignited. Immediately after the flight any residue in the box should be removed.

TITANIUM TETRACHLORIDE

The handling of titanium tetrachloride ($Ti\ Cl_4$) presents many difficulties. Instructions for its use are given in reference 11. This reference also describes the chemical reaction of titanium tetrachloride as follows: "When the liquid comes in contact with average air it forms a hydrate ($Ti\ Cl_4 \cdot 5H_2O$). This is perfectly stable and gives a dense smoke. However, in atmosphere of greater than 60 per cent humidity the smoke absorbs water rapidly, deliquesces, forming liquid drops, and then hydrolyzes rather slowly giving HCl. With perfectly dry air titanium tetrachloride forms no smoke. With very small amounts of water a dense smoke of the hydrate is formed."

The generator used on the right wing of a Fairchild cabin monoplane (FC2W-2) is shown in Figure 9. In Figure 10 the details of the same installation are given. A container was located in the mouth of an air scoop and liquid from it was led to the throat of the scoop by a tube in the free end of which was placed a tapered stopper. Liquid could not flow from the container when the stopper was removed unless air pressure of from 2 to 8 pounds was applied to the space in the container above the liquid. The entrance of the air tube into the container was sealed with vaseline before the container was filled with liquid. This seal was broken when pressure was applied but prevented liquid getting into and clogging the tube prior to that time.

The smoke formed by the mixing of the liquid released in the throat with the air entering the scoop was carried into a smoke chamber in the wing. The smoke flowed out of the chamber through equally spaced slots in the upper surface of the wing between the spars. Any or all of the slots could be closed by covering them with fabric.

Another generator identical in principle with this one but with a difference in the manner of smoke distribution (fig. 11) has been used for test work on another airplane. (Reference 12.) In this case the smoke was generated in the throat of a Venturi that was free to swivel and thus place a stream of smoke in the direction of the air flowing past it. (Fig. 12.) The stopper in the liquid-discharge tube was replaced by a plug of vaseline which was forced out by the application of air pressure.

In flight on the Fairchild, using the generator previously described, pressure was applied to the liquid container at the same time that the stopper was removed. Once the smoke flow was established moving pictures were taken at various angles of attack in glide and level flight. To do this a portion of the roof of the cabin of the airplane had to be removed so that an observer could view the upper surface of the wing. In order to assure a uniform dark background a vertical fin was mounted parallel to the direction of flight and outboard of the slots. Both it and the wing were painted flat red except that white lines perpendicular and parallel to the direction of flight were painted through the slots that were open.

The pictures shown in Figures 13, 14, 15, and 16 are enlargements of representative frames taken from the film. In the reproduction of all the smoke pictures obtained in flight there was a definite loss of detail and retouching of the pictures was necessary. However, the final reproductions compare favorably with the original negatives. Figures 13 and 14, taken without the fin background, show the smoke emitted from 5 slots at 2 angles of attack. Figures 15 and 16, taken with the fin background, show the smoke emitted from each of 2 slots at 5 angles of attack.

This method of generating smoke proved quite satisfactory and gave no trouble when care was used in preparing the installation for flight. The period of time over which smoke could be generated varied from 2 to 6 minutes, depending upon the number of slots open and the atmospheric conditions. It is evident that the time could also be varied by changing the capacity of the liquid container. The velocity of the smoke at the slots was dependent upon the size and arrangement of the air passages and the number of slots open. The density of the smoke depended upon its velocity, the humidity of the atmosphere, and the pressure applied to the liquid in the container.

Inconveniences are encountered in handling the liquid in a relatively humid atmosphere. When its surface is exposed smoke rises from it and a precipitate is formed around the edge of the container. Thus small tubes containing liquid and air become clogged. The container and the tube in which the liquid is to be placed must be thoroughly cleaned and dried before the generator is used, and the stopper should allow no leakage. As smoke can get into the air-pressure tube it too is subject to clogging and must be thoroughly cleaned after each flight.

Care should be taken by those handling the liquid to prevent spilling. The fumes are not particularly injurious but liquid on the body may cause painful burns. The possibility of damage caused by hydrochloric acid depositing on metal parts of the airplane must be guarded against by properly locating the smoke generator and by the use of acid-proof paint. In addition to these precautions, throughout the present tests the wing was washed after each flight. There was no indication of damage to the airplane at the end of the tests.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 17, 1932.

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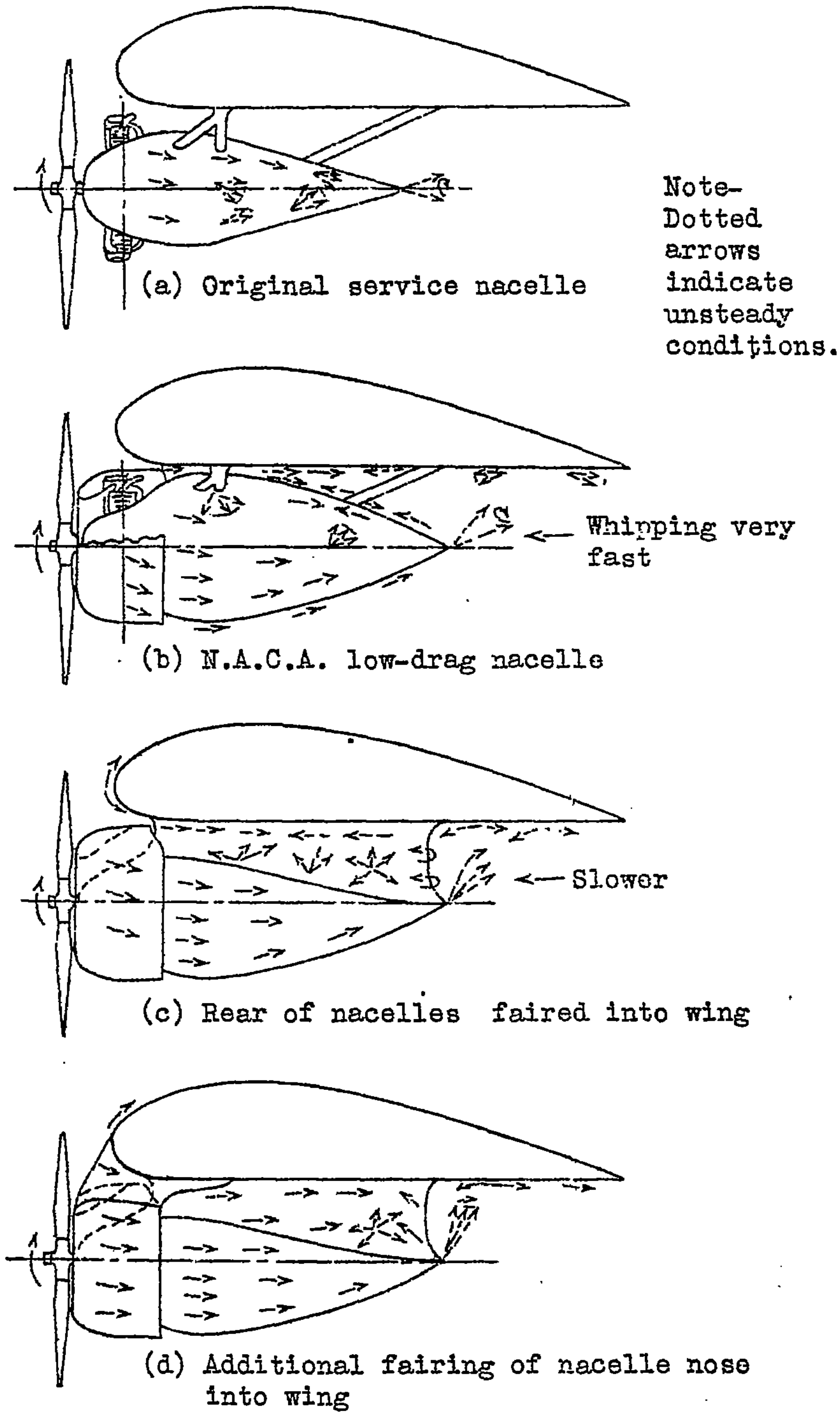


Fig. 1 Air flow around variously-faired nacelles as shown by streamers observed during flight.

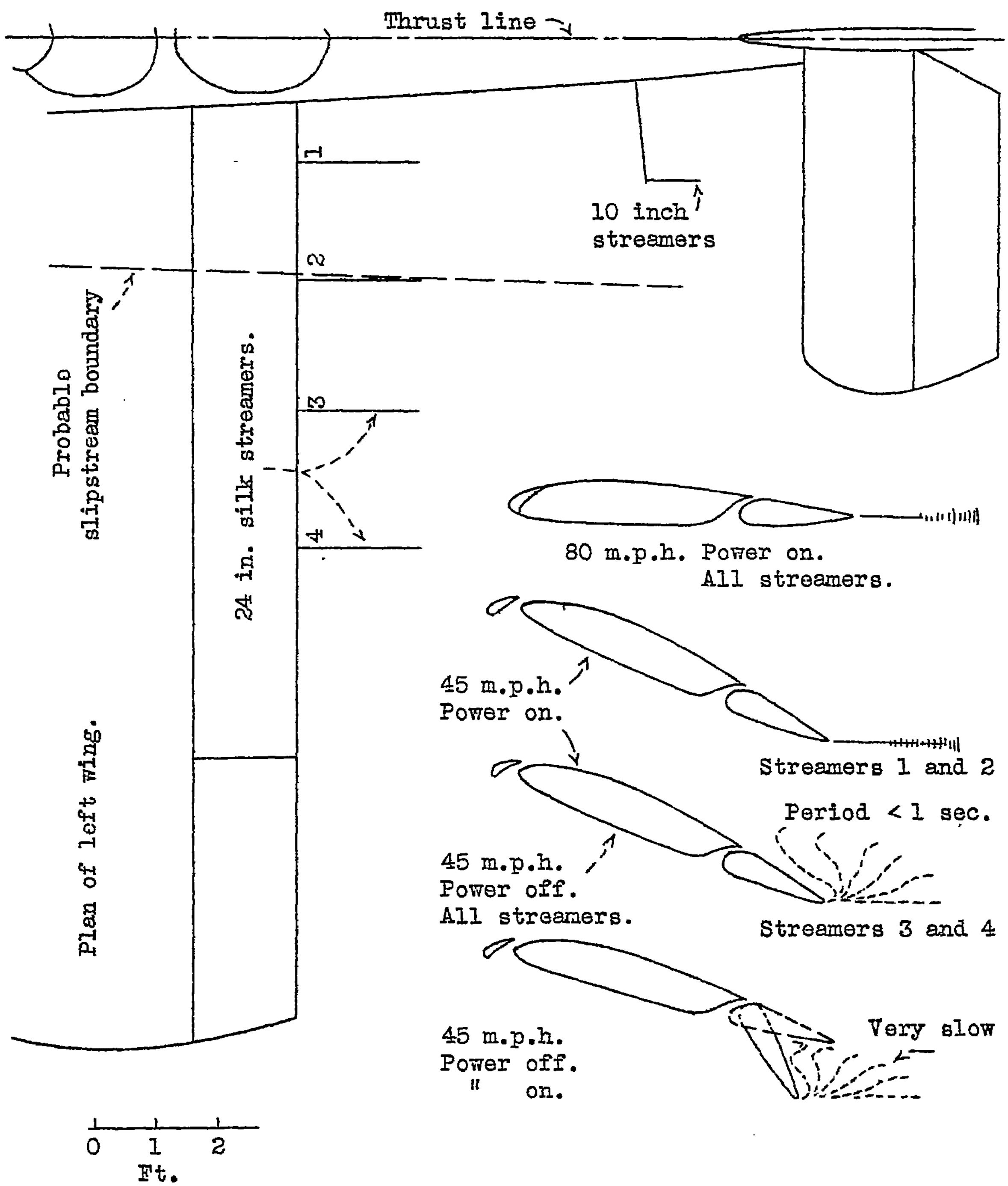


Fig. 2 Air flow behind wing as shown by streamers. Low-wing monoplane with slots and flaps.

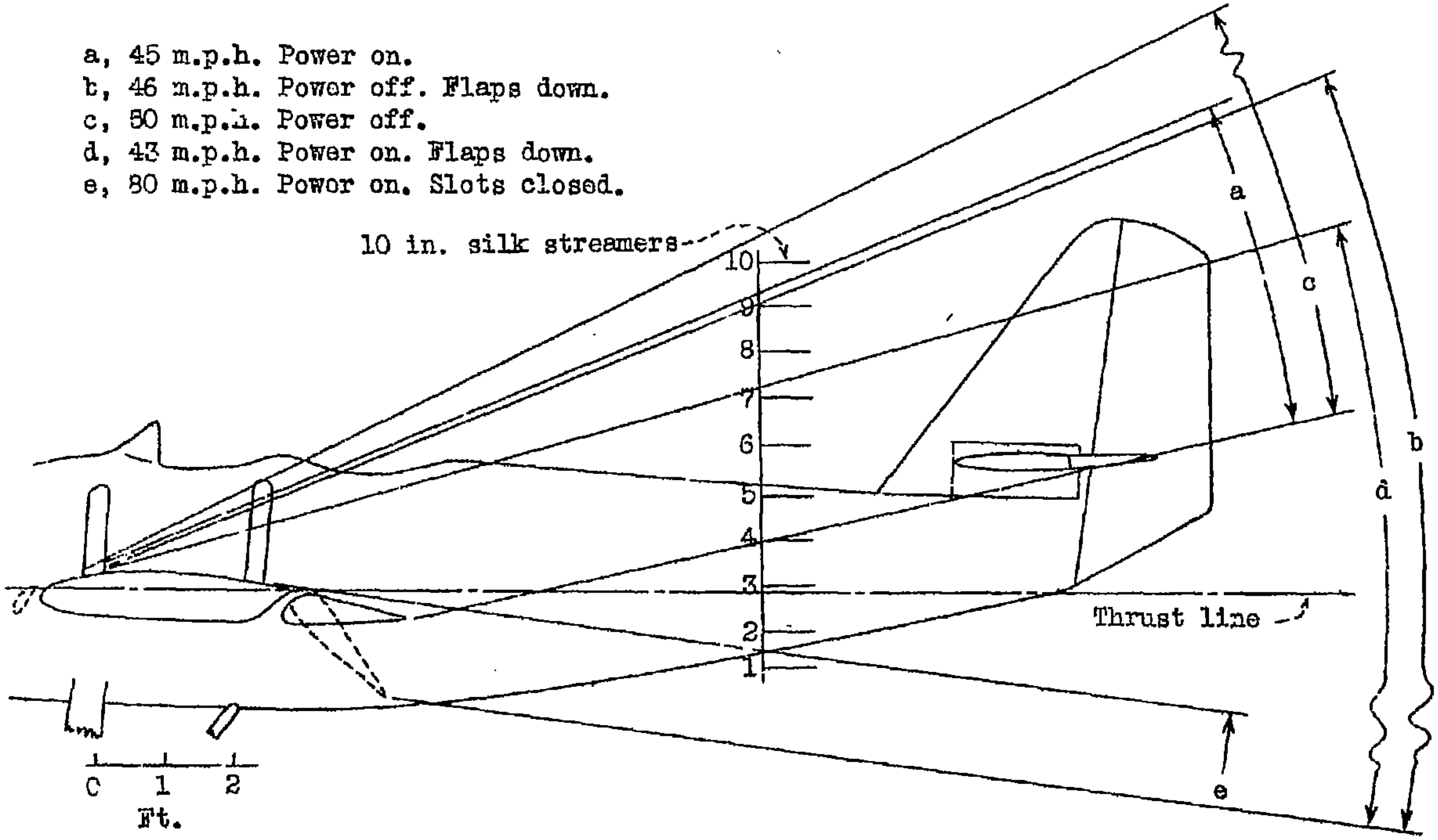
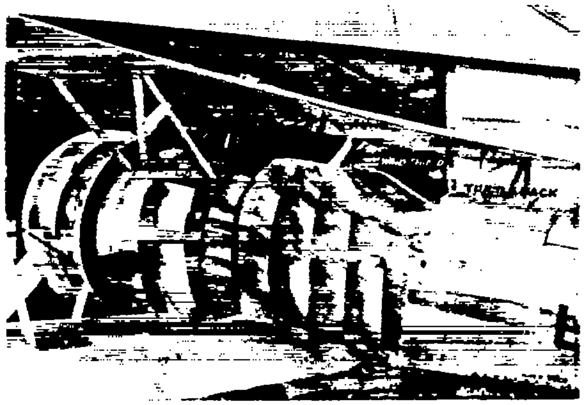
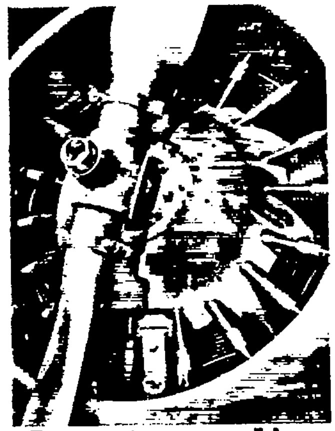


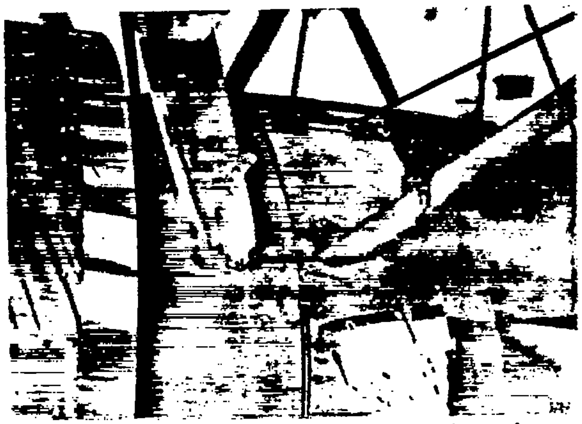
Fig. 3 Turbulent regions in vicinity of tail as shown by streamers.



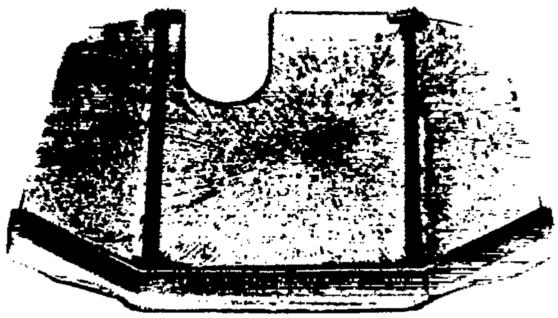
Fuselage



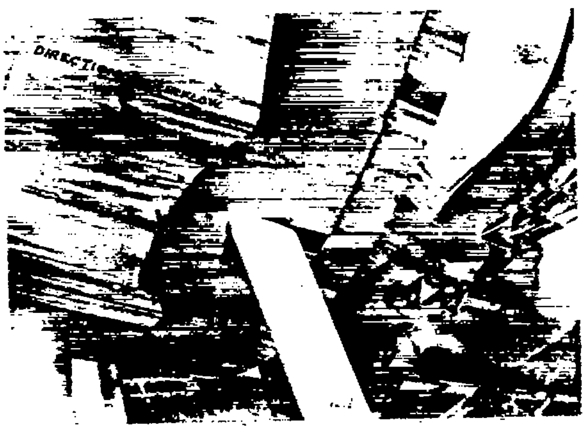
Inner nose cowling



Left forward cabane struts at fuselage



Front view of windshield

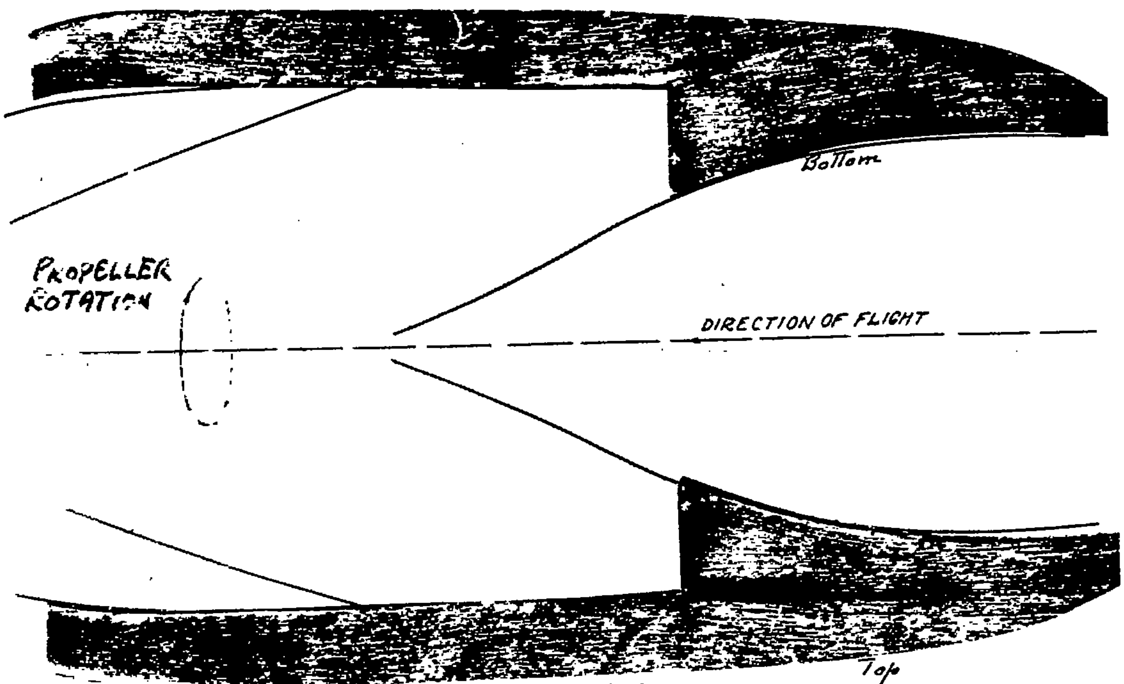


Left forward landing gear strut at fuselage

Top view of turtleback

Fig. 4 Lampblack and kerosene patterns obtained at 165 m.p.h. in level flight on Curtiss XF7C-1 airplane.

Fin perpendicular to surface of fuselage and cowling



Surfaces of fin

Fig. 5 Lampblack and kerosene patterns of air flow around N.A.C.A. cowling on Curtiss XF7C-1 airplane at 165 m.p.h.

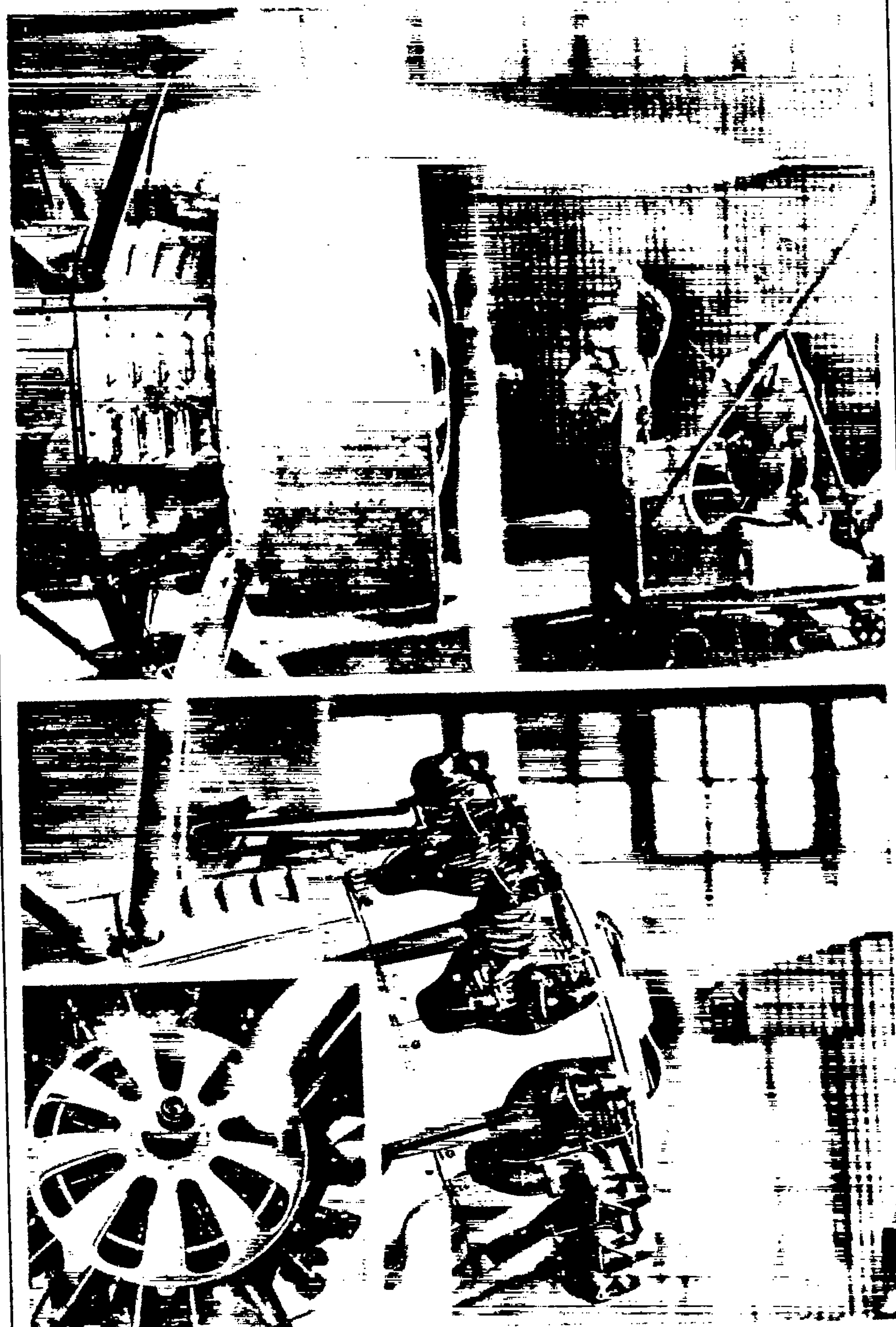


Fig. 6 Kersene smoke passing through propeller plane of Curtiss XF7C-1 airplane.

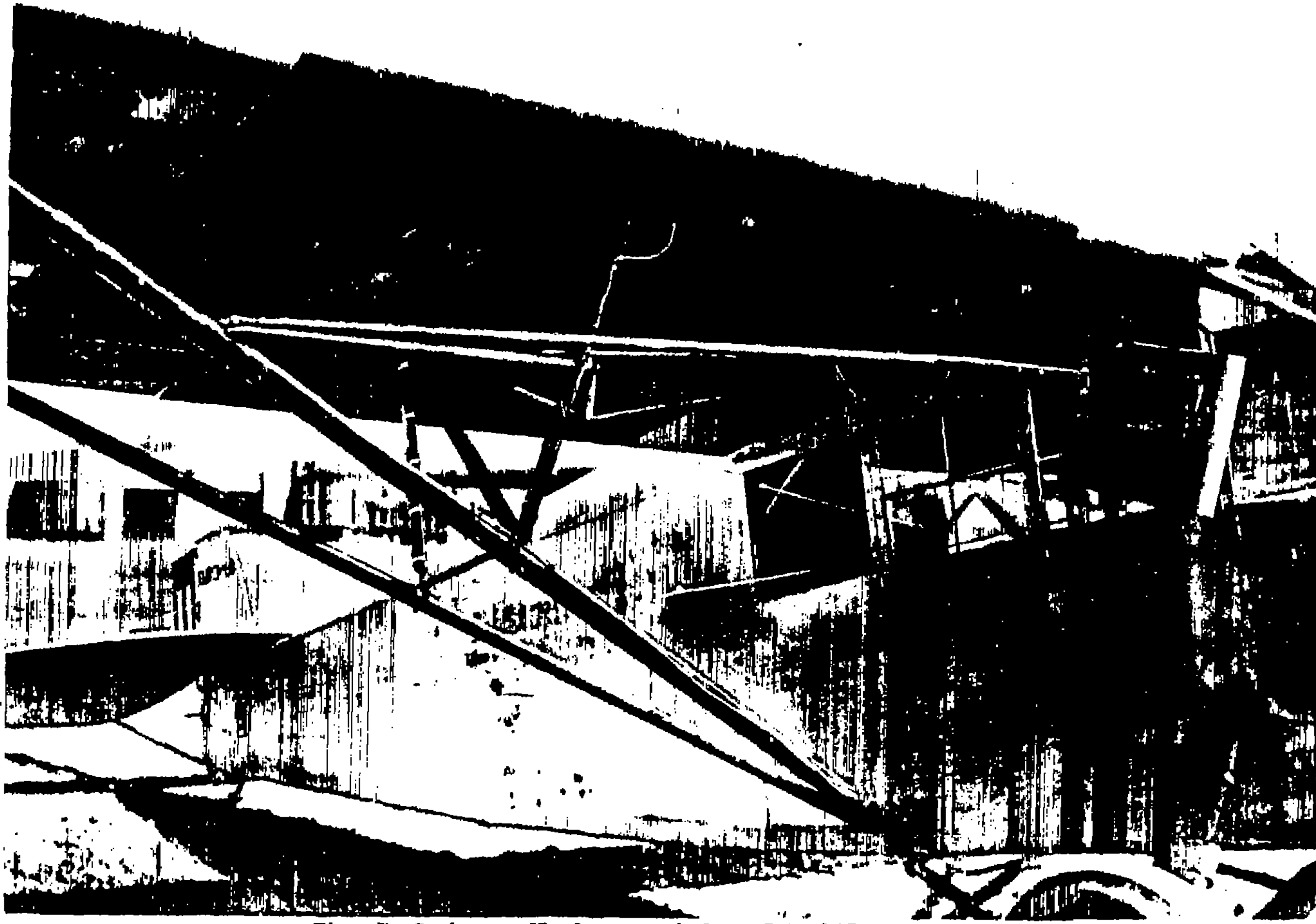


Fig. 7 Smoke-candle box mounted on Fairchild cabin monoplane

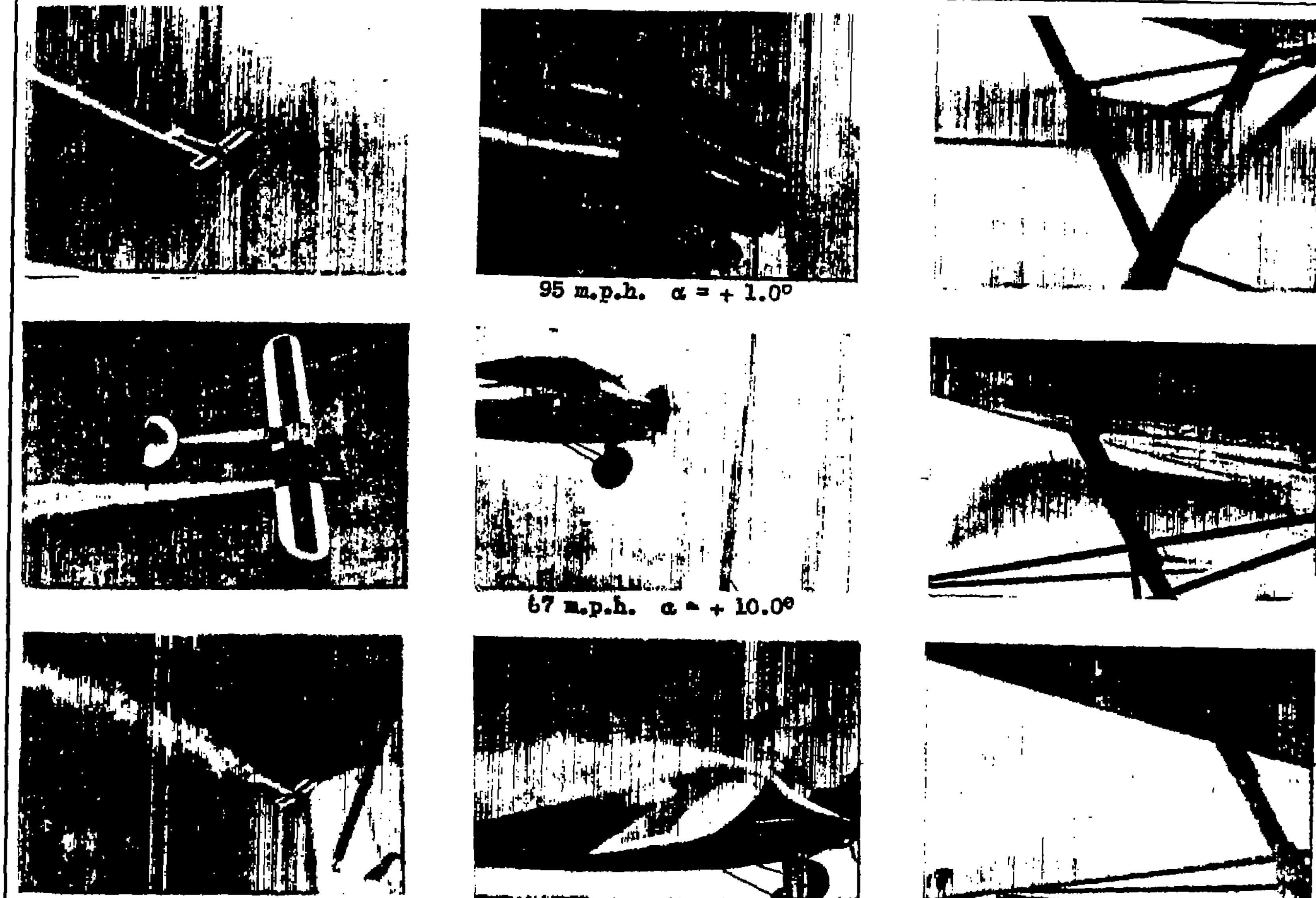


Fig. 8 Smoke produced in flight by candles mounted on Fairchild cabin monoplane

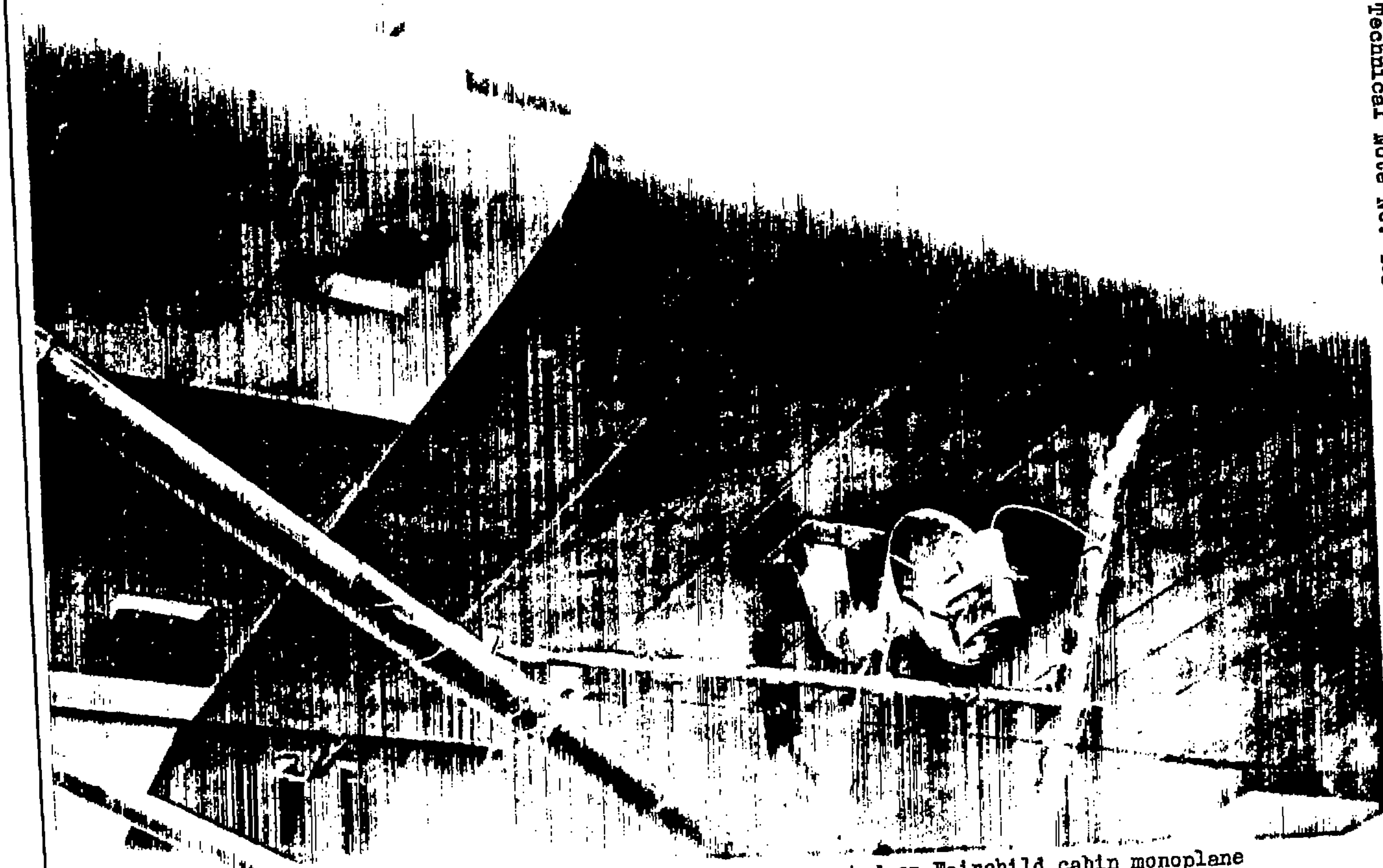


Fig. 9 Titanium tetrachloride smoke generator mounted on Fairchild cabin monoplane

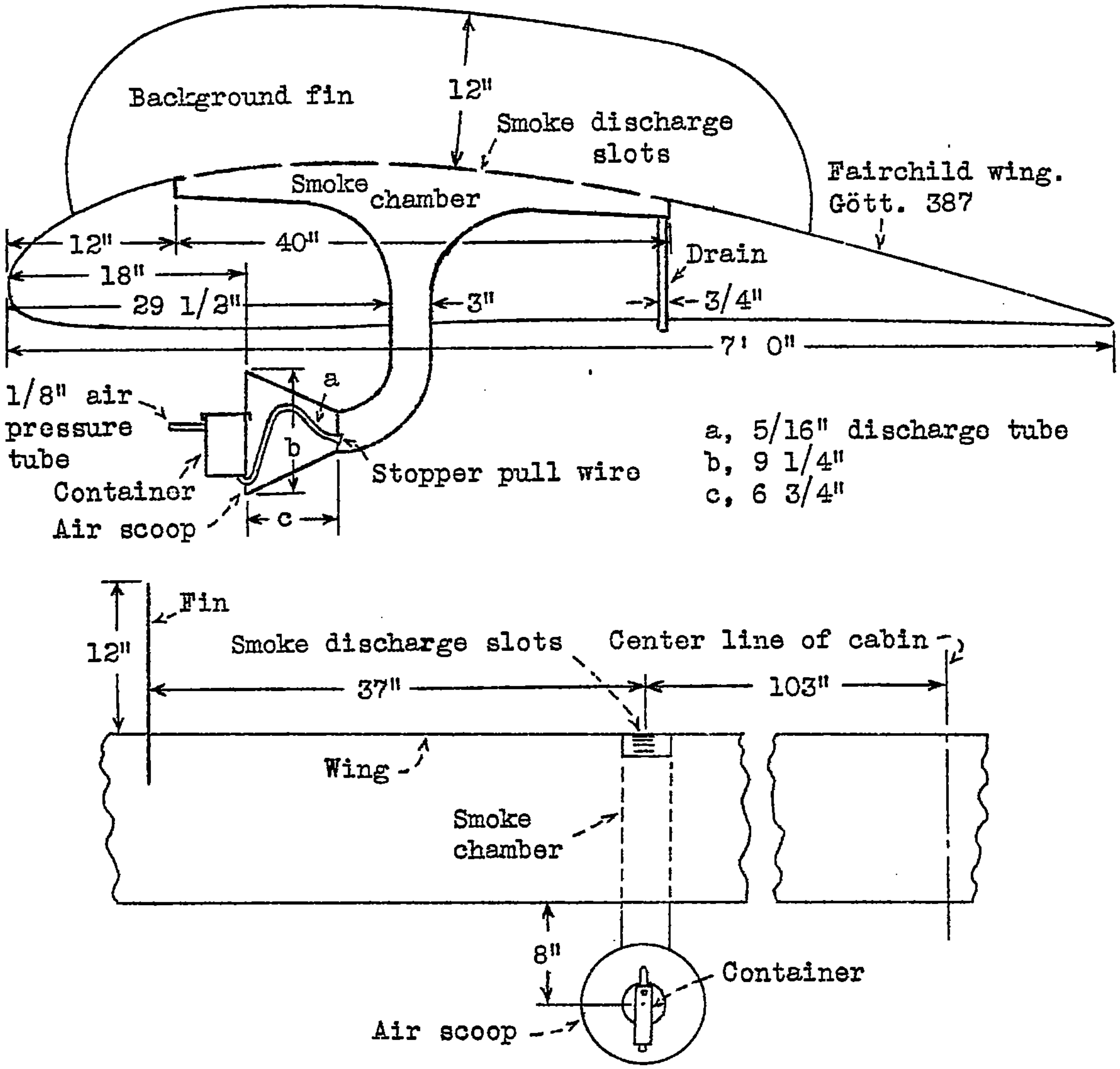


Fig. 10 Sketch of titanium tetrachloride smoke generator mounted on wing of Fairchild cabin monoplane.

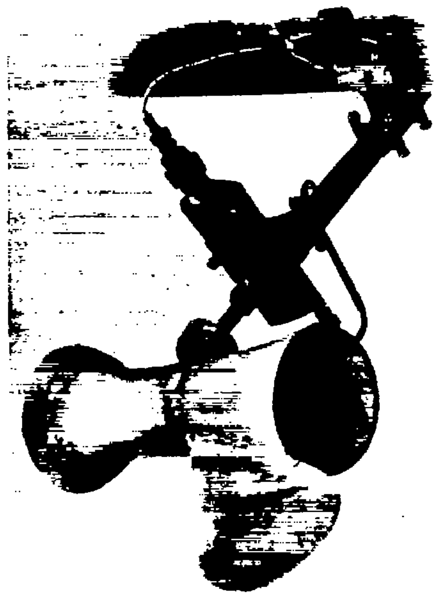


Fig. 11 Titanium tetrachloride smoke generator with swivel-type distributor

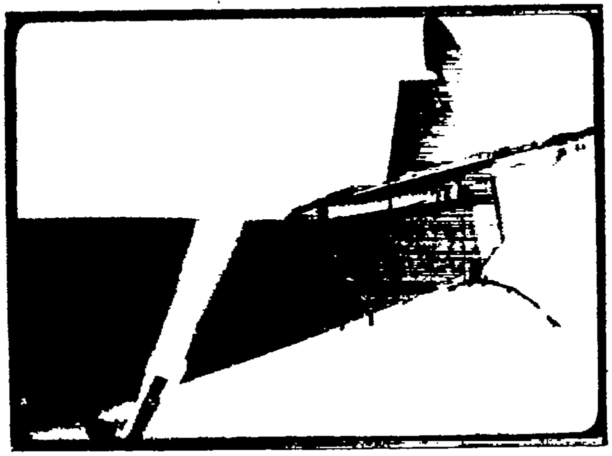
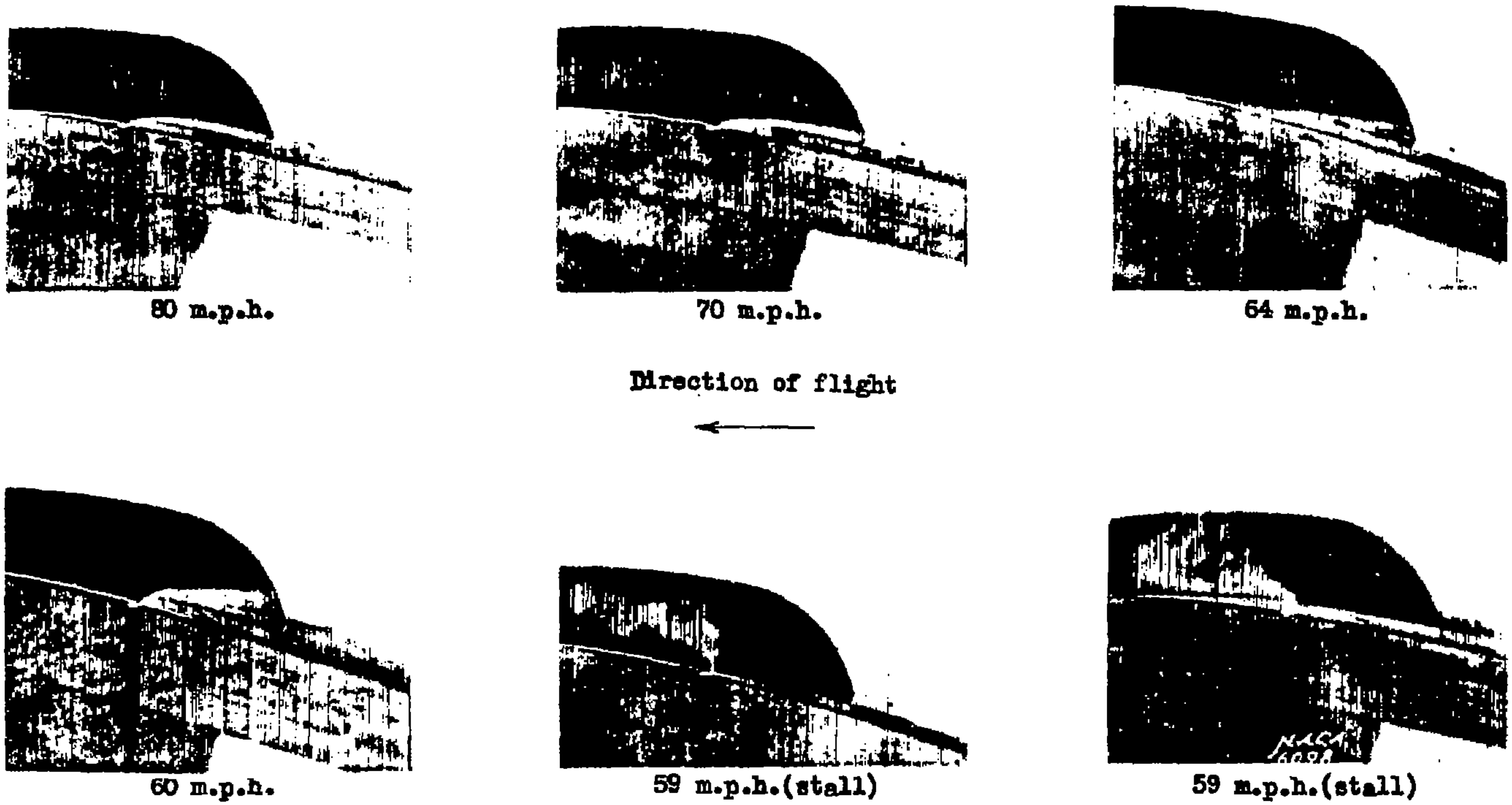


Fig. 12 Smoke flow in spin using swivel-type distributor.

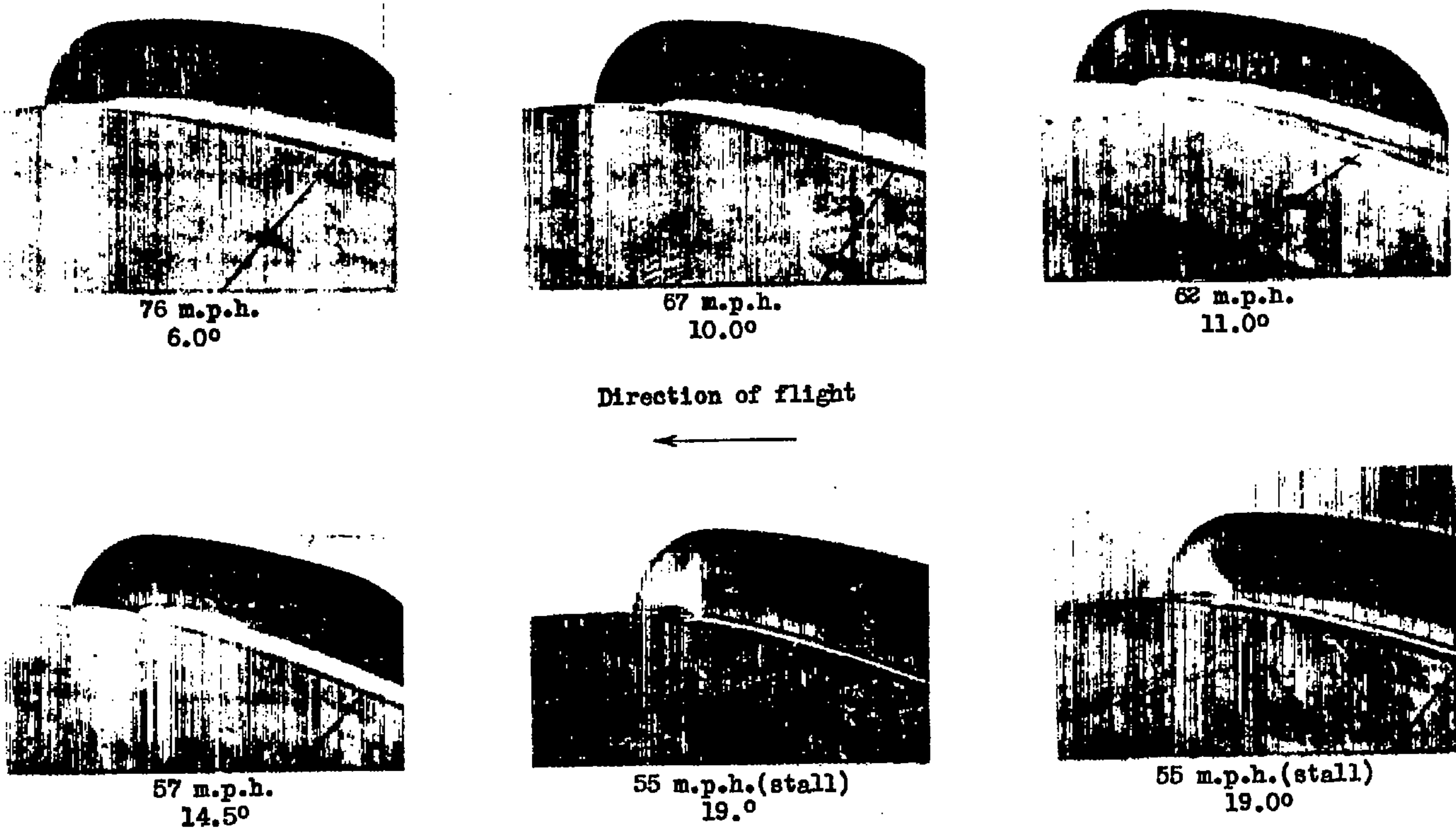
Fig. 13 Smoke flow over wing of Fairchild cabin monoplane with 5 slots open at 14° angle of attack. (Cirrus clouds in background should not be confused with the smoke.

Fig. 14 Smoke flow over wing of Fairchild cabin monoplane with 5 slots open at 18° angle of attack.



Smoke source at 58% chord. (Goet. 387)

Fig. 15 Smoke flow over wing of Fairchild cabin monoplane in glides



Smoke source at 34% chord.(Göet 387)

Fig. 16 Smoke flow over wing of Fairchild cabin monoplane in level flight.